

WHAT IS CLAIMED IS:

1 1. A method of continuously determining operating
2 parameters of a rod pump used in oil or gas
3 production, the rod pump including a rod string
4 carrying a downhole pump and a drive system including
5 an AC electrical drive motor having a rotor coupled to
6 the rod string through a transmission unit, the rod
7 string including a polished rod, said method
8 comprising the steps of:

9 determining values of torque and velocity inputs
10 to the pump;

11 using the torque and velocity values to calculate
12 one or more values representing the performance of the
13 pump; and

14 using values of parameters related to the
15 geometry of the rod pump and at least one of said
16 performance values to calculate values of an operating
17 parameter of the rod pump.

1 2. The method according to claim 1, wherein
2 determining the torque and velocity values includes
3 continuously measuring electrical voltage applied to
4 the drive motor and electrical current drawn by the
5 drive motor, and using the measured values of
6 electrical voltage applied to the motor and electrical
7 current drawn by the motor to calculate at least one
8 value for a parameter selected from the group
9 consisting of motor torque and motor velocity.

10 3. The method according to claim 1, wherein said
11 operating parameter is polished rod position, and
12 wherein calculating said operating parameter includes
13 the steps of deriving a crank angle value from the
14 motor velocity values, and using the crank angle value

15 in calculating values of the position of the polished
16 rod.

1 4. The method according to claim 3, wherein deriving
2 the crank angle value includes integrating with
3 respect to time, the motor velocity values to get a
4 value indicative of a position which, when combined
5 with an overall gear ratio of a gearbox of the
6 transmission unit and a reference position produces a
7 value corresponding to the angular position of an
8 output crankshaft of the transmission unit.

1 5. The method according to claim 1, wherein said
2 operating parameter is polished rod load, and wherein
3 calculating the values of said operating parameter
4 includes the steps of deriving a crank angle value
5 from the motor velocity values, and using the crank
6 angle value and the values of electrical torque in
7 calculating values of polished rod load.

1 6. The method according to claim 5, including using
2 the values of parameters representing the geometry or
3 the rod pump together with the crank angle value to
4 calculate a torque factor.

1 7. The method according to claim 5, including using
2 the overall gear ratio of the transmission unit to
3 calculate from the electrical torque value, the output
4 torque of the transmission unit.

1 8. The method according to claim 5, including the
2 steps of:
3 using the parameter values related to the
4 geometry of the rod pump and motor velocity values to

5 derive a value of rotary weight torque for the
6 crankshaft;
7 using parameter values representing the geometry
8 of the rod pump and a torque factor derived from the
9 parameter values representing the geometry of the rod
10 pump and the crank angle to calculate a value of load
11 inertia for the drive motor;
12 deriving from the motor velocity values, values
13 of instantaneous acceleration of a rotor of the drive
14 motor;
15 and using the rotary weight torque value, the
16 load inertia value, the motor acceleration values, the
17 torque factor, the electrical torque value and at
18 least one characteristic value of the rod pump to
19 calculate instantaneous load for the polished rod.

1 9. The method according to claim 8, wherein deriving
2 the rotary weight torque value includes the steps of
3 combining the crank angle value and a counterweight
4 angle value to produce an angular position value; and
5 multiplying the angular position value by a factor
6 related to rotary weight.

1 10. The method according to claim 8, wherein
2 calculating the load inertia value includes the steps
3 of combining the torque factor and a value
4 corresponding to the weight of the beam weight at the
5 polished rod to produce an inertia value, combining
6 the inertia value with a value indicative of the
7 inertia of a counterweight of the rod pump, and
8 combining the result with a value corresponding to the
9 inertia of the rotor of the drive motor.

1 11. The method according to claim 8, wherein deriving
2 the acceleration value includes differentiating the
3 motor velocity value with respect to time.

4 12. The method according to claim 1, wherein deriving
5 the torque values includes obtaining an estimate of a
6 value of stator flux, and using the stator flux
7 estimate value and the measured current to calculate
8 the torque value.

1 13. The method according to claim 1, wherein
2 determining the motor velocity values includes
3 obtaining an estimate of electrical frequency,
4 obtaining an estimate of slip frequency, and using the
5 estimated values of electrical frequency and slip
6 frequency and the measured current to obtain the motor
7 velocity value.

1 14. The method according to claim 5, wherein the
2 first and second operating parameters are
3 instantaneous position and load of the polished rod,
4 and further including using the estimated values of
5 position and load for the polished rod to obtain a
6 surface dynamometer card for the rod pump, and
7 deriving from the surface dynacard a downhole
8 dynamometer card for the rod pump.

1 15. The method according to claim 14, wherein
2 deriving the downhole dynamometer card includes using
3 a wave equation to model the force trajectory along
4 the rod string in distance and time, and wherein
5 boundary conditions for the wave equation include
6 polished rod load and displacement as a function of
7 time.

1 16. A method of continuously determining rod position
2 and rod load for a rod of a rod pump used in oil and
3 gas production for use in real-time control of the rod
4 pump, the rod pump including a rod string, and a drive
5 system including an AC electrical motor having a rotor
6 coupled to the rod string through a transmission unit
7 for reciprocating a downhole pump, the rod string
8 including a polished rod, said method comprising the
9 steps of:

10 continuously measuring the voltage applied to the
11 drive motor to produce an electrical voltage output
12 signal;

13 continuously measuring the current applied to the
14 drive motor to produce an electrical current output
15 signal;

16 deriving values of instantaneous electrical
17 torque from the electrical voltage output signal and
18 the electrical current output signal;

19 deriving values of instantaneous motor velocity
20 from the electrical voltage output signal and the
21 electrical current output signal;

22 determining a crank angle position for the motor;
23 using values of parameters related to geometry of
24 the rod pump to calculate values for instantaneous
25 positions of the polished rod for related angular
26 positions of the crank; and

27 using at least the crank velocity value and at
28 least one of the electrical torque values to produce
29 an instantaneous value of the load of the polished
30 rod.

1 17. The method according to claim 16, including the
2 steps of:

3 using values of parameters related the geometry
4 of the rod pump and the motor velocity values to
5 derive a value of rotary weight torque for the
6 crankshaft;

7 using values related to the geometry of the rod
8 pump and a torque factor derived from the geometry of
9 the rod pump and the crank angle to obtain a value of
10 load inertia for the drive motor;

11 deriving from the motor velocity values, values
12 of instantaneous acceleration of the rotor of the
13 drive motor; and

14 using the rotary weight torque value, the load
15 inertia value, the motor acceleration values, the
16 torque factor, the electrical torque value and at
17 least one characteristic value of the rod pump to
18 calculate instantaneous load for the polished rod.

1 18. The method according to claim 17, wherein
2 calculating the rotary weight torque includes the
3 steps of combining the crank angle value and a
4 counterweight angle to produce an angular position
5 value; and multiplying the angular position value by a
6 factor related to rotary weight.

1 19. The method according to claim 17, wherein
2 calculating the load inertia value includes the steps
3 of combining the torque factor and a value
4 corresponding to the weight of the beam weight at the
5 polished rod to produce an inertia value, combining
6 the inertia value with a value indicative of the
7 inertia of a counterweight of the rod pump, and
8 combining the result with a value corresponding to the
9 inertia of the rotor of the drive motor.

1 20. The method according to claim 17, wherein
2 deriving the acceleration value includes
3 differentiating the motor velocity value with respect
4 to time.

5 21. The method according to claim 16, wherein
6 obtaining the electrical torque values includes
7 obtaining an estimate of a value of stator flux, and
8 using the stator flux estimate value and the
9 electrical current output signal to obtain the
10 electrical torque value.

1 22. The method according to claim 16, wherein
2 obtaining the motor velocity values includes obtaining
3 an estimate of electrical frequency, obtaining an
4 estimate of slip frequency, and using the estimated
5 values of electrical frequency and slip frequency and
6 the electrical current output signal to obtain the
7 motor velocity value.

1 23. The method according to claim 16, and further
2 including using the estimated values of position and
3 load for the polished rod to obtain a surface
4 dynamometer card for the rod pump, and deriving from
5 the surface dynamometer card a downhole dynamometer
6 card for the rod pump.

1 24. A method of optimizing the performance of a rod
2 pump used for transferring fluid within a fluid
3 system, the rod pump including a rod string carrying a
4 downhole pump, and a variable drive coupled to the rod
5 string for reciprocating the rod string within the
6 fluid system, the method comprising the steps of:

7 determining torque and velocity inputs to the rod
8 pump;
9 using the torque and velocity inputs to calculate
10 values for one or more operating parameters for the
11 rod pump;
12 using one or more of the operating parameter
13 values to produce command signals; and
14 using the command signals to vary the velocity of
15 the downhole pump to cause the downhole pump to
16 closely follow the polished rod position while
17 limiting tensile and compressive forces excursions in
18 rod load as the rod string is being reciprocated.

1 25. The method according to claim 24, wherein
2 determining torque and velocity inputs includes the
3 steps of:

4 measuring electrical voltage applied to a drive
5 motor of the variable drive and electrical current
6 drawn by the drive motor; and

7 using the measured values of electrical voltage
8 and current to calculate values of motor torque and
9 motor velocity for the drive motor.

1 26. A method of controlling the performance of a rod
2 pump used for transferring fluid within a fluid
3 system, the rod pump including a rod string carrying a
4 downhole pump, the rod string including a polished
5 rod, the method comprising the steps of:

6 determining values of torque and velocity inputs
7 to the pump;

8 using the torque and velocity values to calculate
9 values for one or more operating parameters for the
10 rod pump;

11 using one or more of the operating parameter
12 values to produce command signals; and
13 using the command signals to vary the velocity of
14 the pump to at least limit excursions in rod load to
15 preset limits.

1 27. The method according to claim 26, wherein the
2 operating parameters include at least one of rod load,
3 rod position and rod velocity.

1 28. The method according to claim 26, wherein using
2 the operating parameter values to produce command
3 signals includes the steps of
4 obtaining a value representing rod load;
5 obtaining a value representing rod position;
6 using the values of rod load and rod position to
7 obtain an estimate of the velocity of the downhole
8 pump; and
9 using the difference between the rod velocity and
10 the downhole pump velocity in producing the command
11 signals.

1 29. The method according to claim 27, wherein using
2 the operating parameter values to produce command
3 signals includes the step of obtaining an estimate of
4 velocity of the downhole pump using at least the value
5 of rod load.

1 30. The method according to claim 29, wherein
2 obtaining an estimate of velocity of the downhole pump
3 includes using at least rod load along with a
4 simulation model to predict the velocity of the
5 downhole pump.

1 31. The method according to claim 30, wherein the
2 simulation model is based on a multi-section model of
3 the rod string.

1 32. The method according to claim 30, wherein the
2 simulation model is based on a wave equation model of
3 the rod string.

1 33. The method according to claim 30, wherein the
2 simulation model is based on a single section model of
3 the rod string.

1 34. The method according to claim 27, wherein using
2 the operating parameter values to produce command
3 signals includes the steps of using one or more of the
4 operating parameter values to calculate a value
5 representing rod load and comparing the rod load value
6 with preset upper and lower load limit values.

1 35. The method according to claim 26, wherein
2 determining torque and velocity inputs includes the
3 steps of:

4 measuring electrical voltage applied to a drive
5 motor of the variable drive and electrical current
6 drawn by the drive motor; and

7 using the measured values of electrical voltage
8 and current to calculate values of motor torque and
9 motor velocity for the drive motor.

1 36. A method of controlling the performance of a rod
2 pump used for transferring fluid within a fluid
3 system, the rod pump including a rod string carrying a
4 downhole pump, and a variable drive including an
5 electrical drive motor coupled to the rod string for

6 reciprocating the rod string; the method comprising
7 the steps of:
8 measuring electrical voltage applied to the drive
9 motor and electrical current drawn by the drive motor;
10 using the measured values of electrical voltage
11 applied to the drive motor and current drawn by the
12 drive motor to calculate values of motor torque and
13 motor velocity for the drive motor;
14 using the values of motor torque and motor
15 velocity to calculate values representing operating
16 parameters for the rod pump;
17 using one or more of the operating parameter
18 values to produce command signals; and
19 using the command signals to vary the velocity of
20 the downhole pump to cause the downhole pump to
21 closely follow the polished rod position while
22 limiting tensile and compressive forces excursions in
23 rod load as the rod string is being reciprocated.

1 37. The method according to claim 36, wherein the
2 operating parameters include at least one of rod load,
3 rod position and rod velocity.

1 38. The method according to claim 36, wherein using
2 the operating parameter values to produce command
3 signals includes the steps of
4 obtaining a value representing rod load;
5 obtaining a value representing rod position;
6 using the values of rod load and rod position to
7 obtain an estimate of the velocity of the downhole
8 pump; and
9 using the difference between the rod velocity and
10 the downhole pump velocity in producing the command
11 signals.

1 39. The method according to claim 37, wherein using
2 the operating parameter values to produce command
3 signals includes the step of obtaining an estimate of
4 velocity of the downhole pump using at least the value
5 of rod load.

1 40. The method according to claim 39, wherein
2 obtaining an estimate of velocity of the downhole pump
3 includes using at least rod load along with a
4 simulation model to predict the velocity of the
5 downhole pump.

1 41. The method according to claim 40, wherein the
2 simulation model is based on a multi-section model of
3 the rod string.

1 42. The method according to claim 40, wherein the
2 simulation model is based on a wave equation model of
3 the rod string.

1 43. The method according to claim 40, wherein the
2 simulation model is based on a single section model of
3 the rod string.

1 44. The method according to claim 37, wherein using
2 the operating parameter values to produce command
3 signals includes the steps of using one or more of the
4 operating parameter values to calculate a value
5 representing rod load and comparing the rod load value
6 with preset upper and lower load limit values.

1 45. A pump control system for controlling the
2 performance of a rod pump used for transferring fluid
3 within a fluid system, the rod pump including a rod

4 string carrying a downhole pump that is reciprocated,
5 the pump system comprising:
6 means for determining values of torque and
7 velocity inputs to the pump;
8 means for using the torque and velocity values to
9 calculate values for one or more operating parameters
10 for the rod pump;
11 means for using one or more of the operating
12 parameter values to produce command signals for
13 controlling the pump to vary the velocity of the pump
14 to limit excursions in rod load to preset limits.

1 46. The pump control system according to claim 45,
2 wherein the means for using the operating parameter
3 values to produce command signals includes means for
4 obtaining a value representing rod load; means for
5 obtaining a value representing rod position; means for
6 using the values of rod load and rod position to
7 obtain an estimate of the velocity of the downhole
8 pump; and means for using the difference between the
9 rod velocity and the downhole pump velocity in
10 producing the command signals.

1 47. The pump control system according to claim 46,
2 including a simulation model for obtaining an estimate
3 of velocity of the downhole pump.

1 48. The pump control system according to claim 47,
2 wherein the simulation model is based on a multi-
3 section model of the rod string.

1 49. The pump control system according to claim 47,
2 wherein the simulation model is based on a wave
3 equation model of the rod string.

1 50. The pump control system according to claim 47,
2 wherein the simulation model is based on a single
3 section model of the rod string.

1 51. The pump control system according to claim 45,
2 wherein the means for using the operating parameter
3 values to produce command signals includes means for
4 using one or more of the operating parameter values to
5 calculate a value representing rod load and means for
6 comparing the rod load value with preset upper and
7 lower load limit values.

1 52. The pump control system according to claim 45,
2 wherein determining torque and velocity inputs
3 includes the steps of:

4 measuring electrical voltage applied to a drive
5 motor of the variable drive and electrical current
6 drawn by the drive motor; and

7 using the measured values of electrical voltage
8 and current to calculate values of motor torque and
9 motor velocity for the drive motor.

1 53. The pump control system according to claim 45,
2 wherein the means for determining torque and velocity
3 inputs to the pump includes sensors for measuring the
4 electrical voltages applied to the motor and currents
5 drawn by the motor and means for using the measured
6 values of electrical voltages applied to the motor and
7 currents drawn by the motor to calculate values of
8 torque and velocity produced by the motor.

1 54. A system for continuously determining operating
2 parameters of a rod pump used in oil or gas
3 production, the rod pump including a rod string

4 carrying a downhole pump driven by an electrical drive
5 motor that is coupled to the rod string through a
6 transmission unit, the system comprising:
7 means for determining values of torque and
8 velocity inputs to the rod pump;
9 means for using the torque and velocity values to
10 calculate one or more values representing the
11 performance of the rod pump; and
12 means for using parameter values related to the
13 geometry of the rod pump and at least one of said
14 performance values to calculate values of at least one
15 operating parameter of the rod pump.